A NEW APPROACH TO ASSESSMENT AND DESIGN OF INSENSITIVE MUNITIONS BY ANALYSIS OF CRITICAL MECHANISMS THAT MAY BE INITIATED BY UNPLANNED STIMULI

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ABSTRACT

It is not possible to comprehensively model the tests used in insensitive munitions (IM) assessment. Neither is it possible to directly correlate small scale (laboratory) tests to the all-up-round (AUR) IM tests. Yet AUR IM tests are extremely expensive and by themselves they give little or no reliable information about the real vulnerability of the round under test. Therefore it is of prime importance that if possible, modelling and laboratory tests are used to increase confidence in IM assessment or ideally to reduce the amount of AUR testing needed.

This paper discusses the present IM assessment method and proposes an improved alternative method that makes maximum use of currently available modelling and laboratory testing technology. This method is based on an initial threat hazard assessment followed by an analysis of the Critical Reaction Initiation and growth MEchanismS (CRIMES) that may ensue. The CRIMES being known, the tests, modelling and analysis necessary to determine the response of the AUR to the threats are identified. The severity of the response is then determined from modelling and small scale tests, and the results are given as probabilities of severity of each possible response (on a continuum from no reaction to detonation). This analysis method uses no AUR testing and the assessment of the AUR to each IM threat can be related to a vulnerability requirement or specification.

The advantages of this approach include:

- prior knowledge of exactly what data will be needed for the assessment of a munition from the design stage;
- greatly increased confidence in the final munition vulnerability assessment;
- cheaper IM assessment;
- knowledge of the reliability of the results;
- the possibility of stating simple IM requirements that allow for the complexities of reality.

INTRODUCTION

This paper addresses first some of the problems connected to the assessment of IM by all up round (AUR) testing, and then presents some results obtained in a recent attempt to validate an alternative assessmnet method that does not rely on AUR testing.

IM Assessment by AUR testing

To design IM, well defined IM requirements are needed together with an ability to asses how well a munition meets IM requirement goals. However, the current IM assessment method (testing two items in certain standardized tests and assigning one of five response types or no reaction) does not allow a real assessment of a munitions IM characteristics because:

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- the items tested may not be representative of the stockpile;
- item to item and test to test variations mean that there may be more than one possible response type to each test;
- the current tests often require subjective analysis in order to assign a response type;
- the test itself is a single scenario chosen among an infinite range of possibilities, and it is not certain to be "worst case".

A discussion of the first point and the problems of statistically valid testing was presented by Kernen and Bodart at the 26th DDESB meeting[1].

A recent example of the second point was raised recently when old double base rocket motors were being destroyed by open burning after removing the fore and aft closures. Many hundreds of such motors had been simply burned out, but on one occasion a motor exploded. In a storage situation, one such unexpected event could be catastrophic due to sympathetic explosions of other stores if one had assumed on the basis of the first hundred or more mild burns that no other reaction could ever occur. Similarly, results published at the ADPA Insensitive Munitions Technology meeting in 1992 showed that even in an instance of well controlled IM testing of simple components, 25% of bullet and fast cook-off tests were not reproducible[2].

Alternative Assessment Methods

In other areas of munition characterisation other assessment methods are used:

- in some areas of safety, probabilistic assessments are made on the basis of modelling and testing (there must normally be $< 1x10^{-6}$ chance of fuses arming accidentally; drop heights and gap tests use 50% probabilities);
- probability and variations in characteristics have been used in performance measurement, e.g. shaped charge jet penetration, and warhead fragment size and velocity;
- in qualification, an assessment is based on accumulated lab. test data, historical precedents, and judgement from "those skilled in the art".

This paper explores the application of these methods (using probability, accepting and characterising response distribution, using testing and modelling) to IM assessment together with a knowledge of the underlying mechanisms than produce the observed responses in IM tests to arrive at realistic judgements of a munition against clearly definable IM requirements.

If it is possible to look at a test and state what can occur in it mechanistically and what factors are important in determining ignition and growth of the energetic material's (EM) reaction in that mechanism then one is a long way towards knowing what the outcome of a test will be. With the addition of some modelling, analogy and empirical relationships, it should be possible to get even closer. Certainly to predict the most likely outcome, and estimate how important in relative terms other outcomes are. This has become possible because there has been considerable growth in qualitative understanding of what happens in IM types of tests. Thus the factors that govern the response of munitions in these tests are well known even if how they quantitatively affect the response is not.

Causes of Responses in IM Tests

A simple example of an analysis of potential reactions in fragment impact could be as follows. The fragment hits the case and sends a shock wave into it and thus the EM. A possible mechanism for a response is SDT. Another mechanism is XDT through shock on damaged material or reflected shocks. If the fragment passes into the EM it imparts its kinetic energy and heat into it. It will cause damage to the EM and may lodge somewhere in the bomb. Now other mechanisms are possible. The work done on the EM could ignite it, or the hot lodged fragment
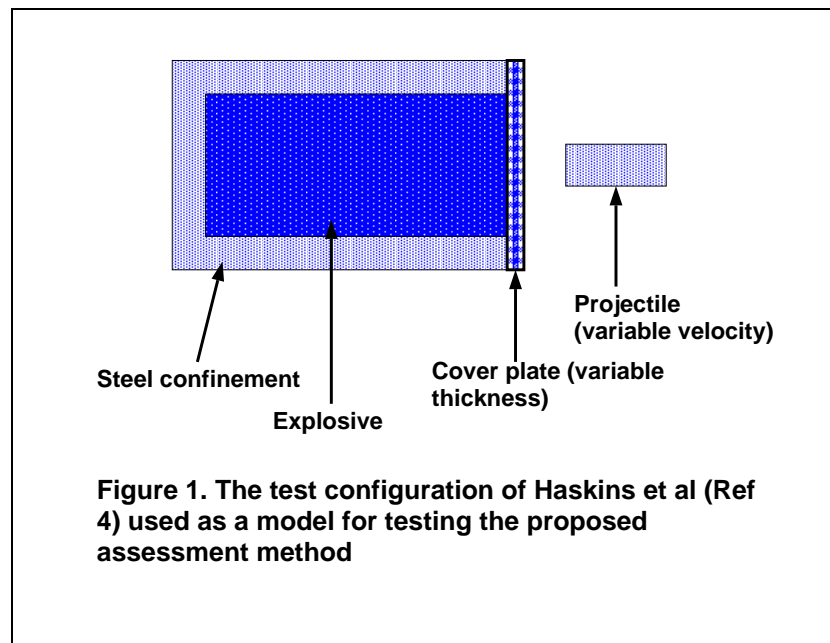
could ignite it. In either case there is burning of the damaged EM with venting through the fragment entrance hole. The outcome depends on the burning characteristics of the EM and the surface area created before and during the burn. There is either a rapid pressure build up leading to an explosion, or no rapid pressurisation, and a mild non-propulsive burn.

Further identification of what might cause a reaction to occur in all of the IM hazard scenarios, and what controls the responses has been studied within the TTCP WAG 11 group amongst others. However, a method does not appear to have been formally proposed in the literature showing how different tests combined with modelling could be used to look at the response likely from each possible mechanism in a given situation, to build up an accurate description of the overall responses that are most likely. NIMIC has undertaken this task and has tried to determine whether a practical IM assessment method based on an analysis of the Critical Reaction Initiation and growth MEchanismS (CRIMES) is possible. If it is ,then there are a number of desirable results from such an assessment, namely:
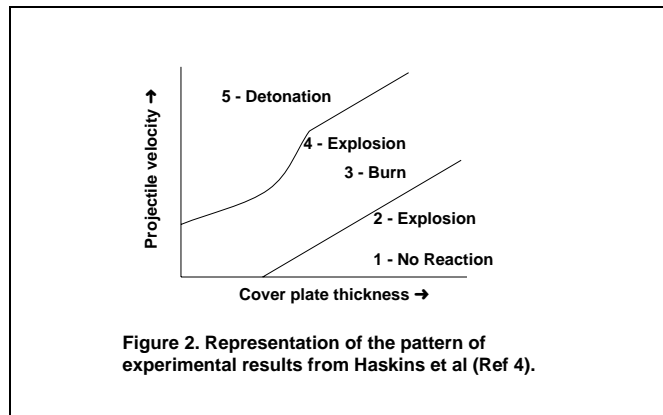
- the determination of the range of possible responses;
- the approximate likelihood of each response;
- knowledge of the factors that influence response variability;
- maximum use of affordable laboratory tests and modelling to make an assessment.

It is the hypothesis of this paper that enough is known of the controlling mechanisms in IM threat scenarios for this approach to be viable as an IM assessment tool. This was shown in part to be reasonable by a simple IM assessment of prototypical munitions as presented in a recent paper[3]. A more rigorous attempt to test the hypothesis is reported below.

VALIDATION RESULTS

Figure 1. The test configuration of Haskins et al (Ref 4) used as a model for testing the proposed assessment method

A paper on fragment impact experiments and modelling was presented at the last detonation symposium by Haskins et al[4] that has served as a model for the attempted validation of the CRIMES methodology. In the paper, cylindrical projectiles were fired over a range of velocities at confined explosive charges with different thicknesses of barrier materials (figure 1). Both the threshold velocities for reaction/no reaction and prompt shock to detonation/other responses were reported together with an indication of the violence of sub-detonative responses from two different explosives (figure 2). In general, the results showed the following pattern of response for a given thickness of cover plate.

Figure 2. Representation of the pattern of experimental results from Haskins et al (Ref 4).

(1) At low projectile impact velocities there was no projectile penetration and no reaction.

(2) At velocities where the projectile just penetrated the explosive cover plate there was often a violent reaction.

(3) At higher velocities the response was generally less violent up to

(4) the highest velocities where shock mechanisms induced violent reactions and detonations.

Using the CRIMES approach, these regimes were investigated with modelling and analogy to other test configurations.

The Ballistic Limit

The limit between regimes (1) and (2) - basically the ballistic limit of the case - was studied using empirical relationships, such as the THOR equation and hydrocode modelling (figure 3). Allowing for estimates of the properties of the steel used, the agreement is reasonable.

The 1st Violent Reaction Zone

Using CRIMES, the violent response in regime (2) was assumed to be primarily due to ignition of the explosive charge whilst still confined by the damaged but unruptured steel case. This is a good example of where the CRIMES approach can be applied but where most commonly used methodologies are unhelpful or too complex. One rigorous solution to assessing what would happen in this scenario is to use hydrocodes for the impact coupled with a chemistry based ignition and growth model and a materials model for the response of the case. This is time consuming, hard to parameterise and possibly technically not possible at present. At the other
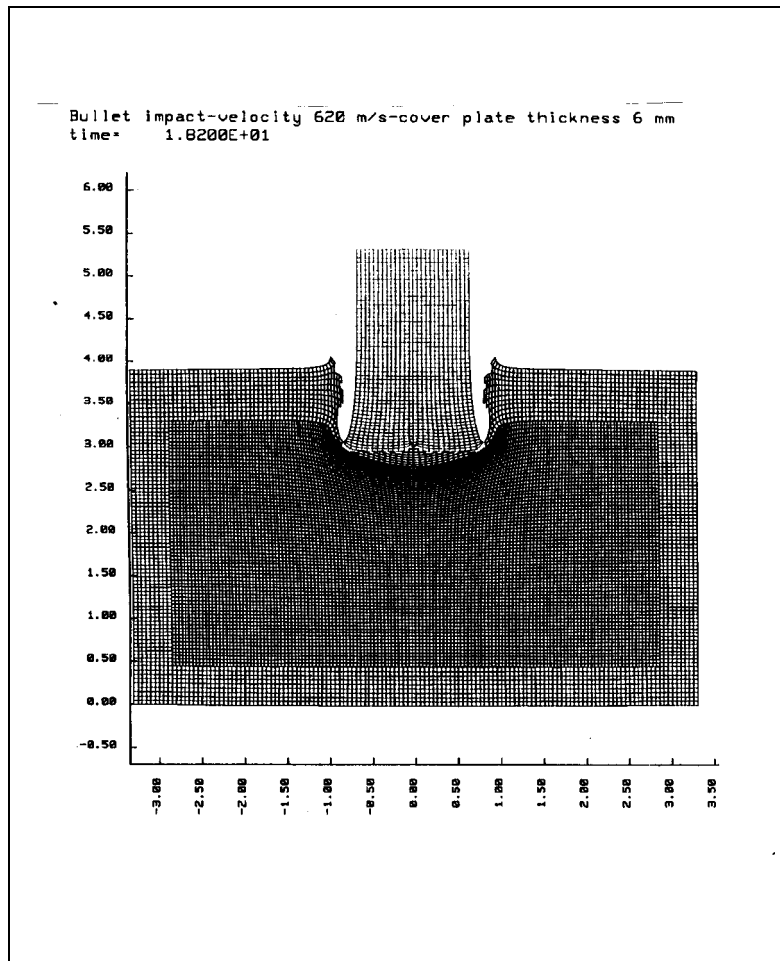

Figure 3. Ballistic limit with Dyna 2D

extreme one could design and validate a test specifically to determine what happens in this situation. This is the expensive option. A reasonable alternative is to assume that in this situation that ignition is a possibility, and that when it occurs the pressure will rise inside the bomb in the same way as it would in a sealed rocket motor or gas generator until such time as the dynamic burst pressure is reached or there is a DDT. Simple DDT criteria have been determined by Boggs, and the dynamic burst pressure can be modelled. The pressure rise rate in the bomb can be modelled using standard propulsion or interior ballistic codes and the sensitivity to of the result to reasonable variations in input parameters can be easily established.

Using such an approach, we determined theoretically that near the ballistic limit of the bomb used by Haskins et al, there was the possibility of reactions from case rupture to violent explosions but no reasonable chance of a DDT, just as had been observed experimentally.

The Mild Reaction Zone

It is often considered that sub-detonative responses in regime (3) below the SDT threshold cannot be modelled. This limits the use of modelling in IM assessment where the requirement is to have a response no worse than burning. One needs to know whether a pressure burst of the case is a possibility or whether the most likely response is burning in place. If there is the potential for a SDT, then clearly the item under consideration is not an IM.

We thought that the potential for explosion could be determined in the case of fragment impact if a bomb penetrated in one or more places (entrance and/or exit holes) is considered to resemble a rocket motor. The holes in the case are nozzles, the holes through the explosive charge are the bore and the hot fragment provides ignition (figure 4). Simply with knowledge of the burning characteristics of the explosive, combined with estimates of the maximum explosive surface area that could be generated by the passage of the fragment it proved
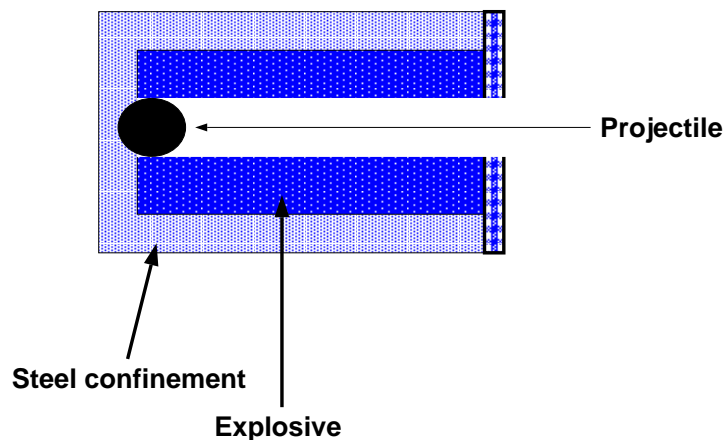

Projectile

Steel confinement

Explosive

Figure 4. The model used to investigate pressure rise rates after fragment impact

possible to determine the potential pressure rise in the bomb in this scenario (figure 5). Our calculations using this model indicated that in the bomb used by Haskins et al the most likely occurrence was a burn in place. This was an observed reaction, but in addition, there were instances of explosions. This would probably have been simulated by introducing either a higher burn rate in the material being pressurised by the passage of the fragment and/or additional burning surfaces from damaged material. However time constraints prevented further investigations of this possibility.
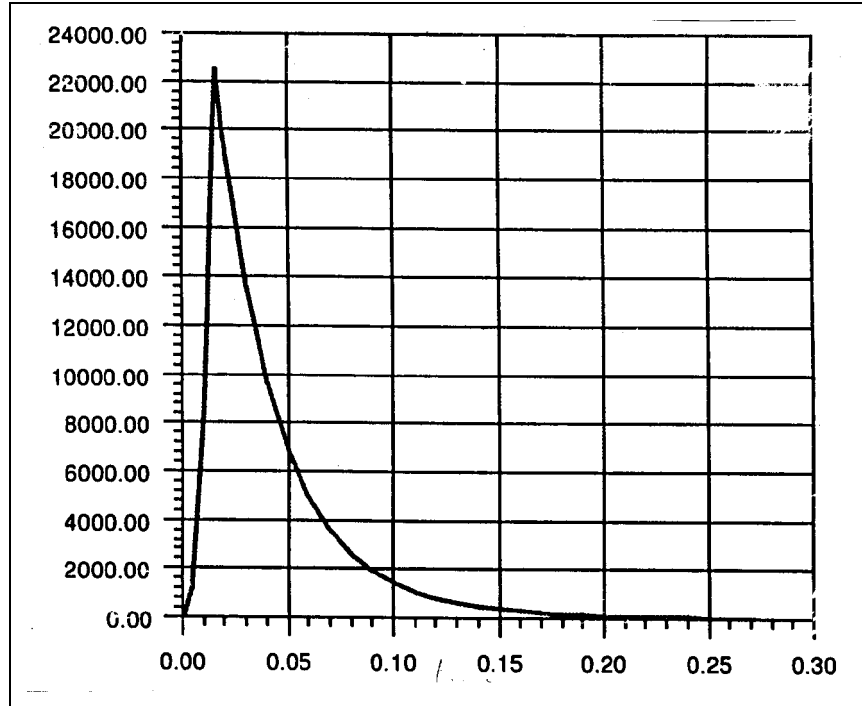

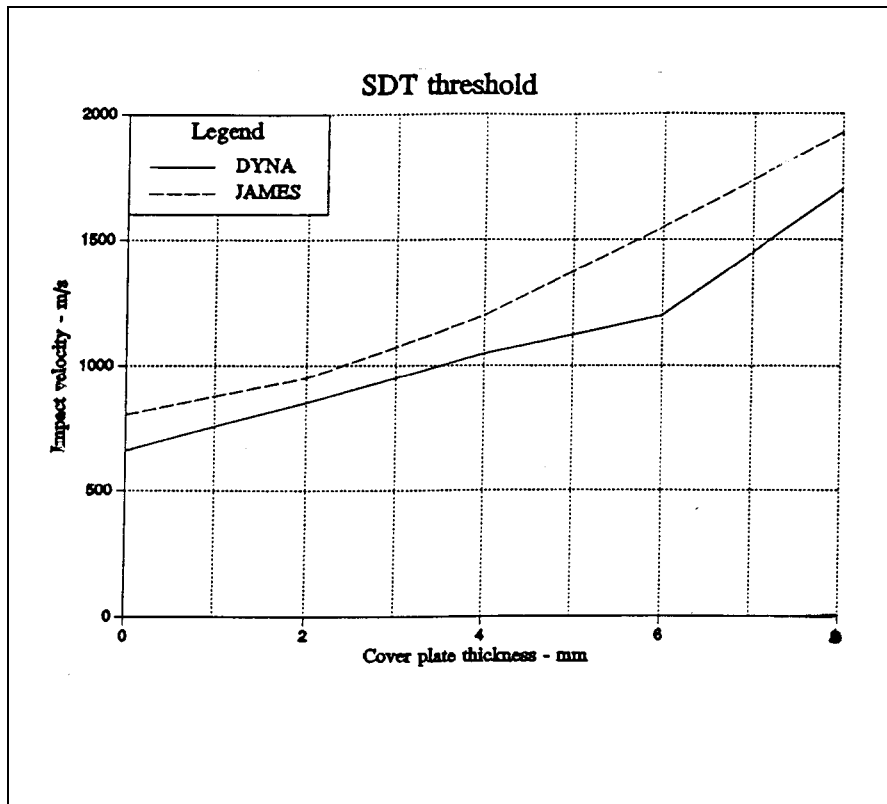
Figure 5. Pressure vs time for explosive with no vent

Figure 6. Initiation threshold for explosive covered by steel - experimental and numerical results

The SDT Threshold

There are a number of techniques of various complexity available to estimate SDT thresholds. We applied both the hydrocode DYNA2D with a Lee-Tarver ignition and growth model, and the empirical relationships of Victor to the results of Haskins et al. Both techniques gave a reasonable estimate of the observed threshold. Victors equations gave the results very quickly and easily up to the point where diverging shock became significant, beyond this it was necessary to use the hydrocode (figure 6). The hydrocode also showed that there was the potential for shock wave reflections to cause detonation at impact velocities just below the simple SDT threshold.

CONCLUSION

We have shown that it is possible to use a selection of models and computer tools to assess the range of responses to be expected from a confined explosive charge submitted to fragment impact. We suggest that the same methodology could be applied to other warhead configurations and thus prevent the need for - or at least add confidence to - full scale munition testing. The same philosophy and assessment methodology is being validated with other types of IM test.

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